Self-Directed Summer Design Experience Across Disciplines and the Globe

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Abstract

During the summer of 2014, the Harvard School of Engineering and Applied Sciences and the Hong Kong University of Science and Technology initiated a multidisciplinary international design experience for the benefit of the student populations of both institutions. The goal of this program was to create an international multidisciplinary team-based research and design project that included exposure to the academic and industrial environments in both Hong Kong as well as the United States (specifically the Boston area). The Harvard-HKUST International Summer Design Experience occurred completely outside of any classroom setting during nine weeks and was co-located in Boston and Hong Kong for four weeks each. The reason to hold this program in both Hong Kong and Cambridge, MA was to give the students a chance to work within and experience both campuses, culturally and geographically. The pedagogical approach was unique, as there was no embedded curriculum and students were able to freely pursue a project in a given topic area that they were interested in. The major topic for this summer was Visible Light Communication systems. In this paper we present the general pedagogical approach to this experience and provide some insights and examples of the effect the program had on students.

Introduction

Harvard School of Engineering and Applied Sciences (SEAS) and the Hong Kong University of Science and Technology (HKUST) initiated a multidisciplinary international design experience for the benefit of the student populations of both institutions. The goal was to provide students with the opportunity to work in interdisciplinary teams and to expose them to the academic and industrial environments in both Hong Kong as well as the United States, primarily the Boston area. Second and third year students were targeted, as they have had at least some introductory classes, to provide a knowledge base to draw upon for the design project. Students were asked to submit an application describing previous engineering experience and their interest in this particular program. The program was offered during the summer, but no academic credit was offered in lieu of a stipend and travel expenses. One of the few requirements imposed on the students was that they would commit themselves completely to this design and research experience. We employed a multi-faceted pedagogical approach that included three distinct elements. These elements were: (1) hands-on design-build-test-refine, (2) total cultural immersion, and (3) allowing students the independence to define goals and manage their own time.

Hands-on experiences enhance learning and satisfaction for students.[1-4] The need to teach design has traditionally been addressed in capstone courses, but there has been a push to introduce design earlier in engineering curricula, such as through first-year introduction to engineering courses or through required design “cornerstone” subjects throughout the undergraduate curriculums across the US. This is partly driven by the requirements that ABET sets for engineering degrees. ABET Criteria 3 (a) through (k) include design explicitly, especially through criteria (c) and (e). The ABET criteria also implicitly include design through requirements for teamwork, ethics, social context, and other broad considerations. Another driving factor to include engineering design in freshman courses is to increase student interest in engineering, improve retention, and improve results in later courses.[5, 6] While ABET learning outcomes for this summer experience were not assessed, the program certainly meets, if not exceeds some of the ABET criteria. In addition, engineering design can only be fully experienced with some sort of realization. Currently, there is almost no other experience that can replace a fabricated prototype to reveal implications of design decisions while revealing complexities and deficiencies within a given prototype or design. Most courses fall short; they focus either on the front end of designs or focus too much on prototyping. This summer experience allowed students to undergo a full design cycle, with the exception of deployment, which was not possible under the circumstance. There are also very few opportunities where students can learn to communicate and think through prototyping to develop concepts, principles, and form within a multi-cultural and multi-disciplinary environment. As such, the learning objectives for the Harvard-HKUST International Design Experience, determined by the instructional staff, are listed below along with the associated ABET Criteria 3: Learning Outcomes:

- Problem Identification: Identify problems with given technology (ABET 3e)
- Decomposition: Decompose a solution into smaller tractable sub-problems and articulate goals (ABET 3e)
- Generate, evaluate, and select concepts from multiple alternatives. (ABET 3c, 3e)
- Prototyping: Utilize physical prototypes to make design decisions. (ABET 3b, 3e)
- Reflection: Critically reflect utilizing multiple forms of communication (oral presentation, poster presentation and formal report writing) (ABET 3e, 3g)
- Communication: Communicate ideas/concepts to audiences in multiple cultures. (ABET 3g, 3h)
- Collaboration: Effectively collaborate in multidisciplinary teams of students, faculty, staff, and outside constituents (ABET 3d)

During a typical course, there can be quite a bit of interaction between students with different cultural and social backgrounds. However, these interactions are set in the context of an academic location (in this case, Cambridge, MA or Hong Kong). Very few of the engineering students at Harvard and Hong Kong, or indeed, most engineering programs, are able to complete a semester abroad due to the strict and extensive requirements for an engineering degree. It was therefore critical that cultural immersion occurred over a substantial period of time.

Finally after the program staff introduced the project, the students were allowed to build their own confidence and efficacy to the point that they could proceed independently. After introducing the program, high-level design concepts, and the project's general focus, the staff transitioned from managing the students' time to working in an advisory capacity. This allowed students to develop and practice project management skills.

Program Motivation and Structure

The Harvard-HKUST International Design Experience was jointly envisioned by faculty members at both institutions to enable a study abroad-like experience for engineering student populations, for whom the opportunity to study abroad is often greatly reduced due to a large number of curricular requirements.[7] As a profession, engineering has become increasingly globalized yet engineering students, as a population, are among those who are least likely to have completed an international educational experience during their college education.[8] As most design and analysis work within industry occurs within project teams, it seemed more pedagogically fitting for an international engineering experience to mirror a team research and design environment as opposed to the lecture/lab environment found within most study abroad programs world-wide. The team-based structure also best allows the transfer of ideas and perspectives among the students. To accomplish this, the summer design experience was constructed as a program made up of multidisciplinary teams not only based on educational diversity but also including cultural and gender diversity. The instructional staff for the summer projects selected a broad program theme, but individual teams were given the freedom to pursue a project topic of interest within that theme. For the 2014 program, the theme was visible light (wavelength) communication systems (VLC). Within this theme, the two student teams chose to focus on two different project areas: a location determination system and a security system, which will be described in greater detail in a later section.

To enable a greater degree of cultural immersion, the summer design experience was hosted at both institutions. In this way, each group of students was afforded the opportunity to spend approximately one month living and working within an academic institution and a culture that is different from their own, as well as one month working at their home institution. Specifically in 2014, the program began in June at HKUST, in which the HKUST students acted as cultural and geographic hosts to the Harvard students. The program began with a weeklong workshop that focused on the design process and simple prototyping skills with the intention that each of the student populations would have a similar level of design competency before continuing on with the summer long project. Fortunately, the *HKUST One Million Dollar Entrepreneurship Competition* coincided with the design workshop, so program participants could interact with competition teams, view their presentations, and use the competition as a focal point for discussions and examples illustrating the topics being presented and discussed during the design workshop. The following week after the design workshop, the students began to explore topics for their summer-long project in VLC. Over the next three weeks, the project teams brainstormed project ideas, down-selected these ideas, and began prototyping project concepts. The instructional staff scheduled regular design reviews with the project teams to discuss progress and provide feedback. Throughout this process, the instructional staff viewed themselves more akin to project mentors than to classroom instructors.

In July, both project teams moved from HKUST to Harvard for the second half of the program. Much like the month spent in Hong Kong, the Harvard students now acted as cultural and geographic hosts to the students from HKUST. For the duration of July, the project team continued to refine and redesign their prototypes in preparation for a final presentation to the members of the Harvard SEAS community. The final presentation included a prototype demonstration, an oral presentation, a written report, and a discussion of the overall summer experience, including non-technical aspects of the experience like cultural events and sightseeing. It is expected that in 2015, the program will begin in June at Harvard and shift to HKUST in July. This will afford Harvard to opportunity to host the design workshop and HKUST the opportunity to host the final presentations.

As discussed above, a significant portion of the first two weeks was dedicated to design thinking as this was one aspect of the program that the instructional staff wanted to reinforce because it was well known that the program participants had little experience in this area. The Harvard SEAS engineering curricula is somewhat different than many engineering programs, as students are exposed to design thinking and methodologies early on. All of the Harvard participants have had at least one engineering course requirement with a significant design task prior to this study abroad experience. Within the Harvard engineering curriculum, students typically take an introductory course on mechanical or electrical engineering during their freshman or sophomore year before declaring their major. These courses require a design project, but there is less focus on design thinking and methodology. This theme is continued in a required team-based design course taken during the junior year, in which the students are more deeply exposed to design methodologies. Within their senior year, students are required to complete an individual senior design (capstone) project, in which they apply their skills and knowledge to a project of their choosing. The Harvard-HKUST International Design Experience is positioned so that students can use the design thinking and project management skills that they have developed throughout the summer, in addition to the introductory design project within their engineering discipline, to better prepare for the more advanced multi-disciplinary project courses required in the junior and senior years. Unlike the Harvard students, the students from HKUST had little or no exposure to design thinking and methods prior to the summer program. The skills gained during this program became immediately useful to the HKUST students as these students were using the summer program to help prepare for their Final Year Projects, which are similar to capstone projects at US universities.

Program Logistics

The Harvard-HKUST Summer Design Experience, like all study abroad programs, has administrative aspects necessary to the execution of a successful program. Early in the planning process, the instructional staff viewed this program as more of an internship-like experience as compared to a typical classroom experience. As such, many of the program logistics may appear different than typical study abroad experiences. Each institution had its own application process and was free to select its own students without approval of the partner institution. At Harvard, there was an information session in the February of 2014, in which the summer program was introduced as well as its goals and structure. An online application was open to students from all academic disciplines that were not graduating in 2014, though given the technical nature of the summer program, students from STEM majors were preferred. Application questions focused on technical skills and courses taken, prior international travel, language skills, and desire to participate in the summer program. The instructional staff intentionally set no prerequisites for application, as 2014 was the first offering of the program. A subset of candidates was interviewed on these topics in order to construct a well-balanced team with a diversity of experience, both technical and non-technical, and who would likely be able work effectively within a multicultural team environment. HKUST used different metrics to select their student participants, which were primarily based on academic performance and the desire to gain team-based project experience before embarking on the HKUST Final Year Projects. The timeline for the 2014 Summer Design Experience is listed as follows:

- February 2014 - Information session for Harvard students
- March 2014 – Harvard Application due and Harvard student selection
- April 2014 – HKUST student selection

- June 2014 – Program begins at HKUST, *HKUST One Million Dollar Entrepreneurship Competition*, Design Workshop, summer project begins
- July 2014 – Program moves to Harvard, summer project continues
- Late July 2014 – Project Presentations and Wrap up

As with all summer programs, there are costs associated with conducting the international design experience. One initial concern of the instructional staff was whether or not students would choose to apply to and participate in the Harvard-HKUST International Design Experience given other opportunities for summer internships in industry or research labs as well as other summer programs offered by Harvard and other universities. As such, the program staff chose to take an internship or REU-like approach with respect to program costs. Upon selection, each student was responsible for a $400 non-refundable program fee, insurance for the duration of time abroad, any passport or visa fees, and transportation to/from their home institution. The program covered round trip airfare from Boston to Hong Kong (or vice versa), room and board in student dorms and dining facilities at each institution, and a $2000 USD (or $HKD equivalent) stipend for each student.

The program staff for the Harvard-HKUST Summer Design Experience consisted of three tenure-track faculty members, two teaching faculty members, one design specialist, and three program administrators between both institutions. To run the Design Workshop and enable consistency between programming at both institutions, the program funded some of the Harvard program staff to be present at HKUST for part of June and some of the HKUST program staff to be present at Harvard in July.

Design Workshop

The program was introduced with a week-long design workshop. The goal of the workshop was to teach students a repeatable process for generating innovative solutions to human-centered problems. Figure 1 shows a graphical representation of the different stages of the design process. Students worked in small groups through exercises that guided them through the stages of investigation, ideation, and prototyping using "divergent" and "convergent" thinking.[9] In the first stage, students learn to "investigate" a problem area: gathering as much information as they can about a problem and then synthesizing it down to a well-defined problem statement using tools like affinity mapping. The next stage, "ideation," is about creative brainstorming techniques to find innovative solutions to a problem. The final stage in the workshop is "prototype," in which students use rapid prototyping techniques to build models of their proposed solutions that indicate the function, interaction, and character of their prototype. All of these hands-on activities illustrate three main points. First, design is iterative - at each stage students are challenged to go back to the original problem area and refine their results based on user feedback. Second, true collaboration requires clear and encouraged communication between a team, and third, a good design requires more than just technical factors - the human needs and economic realities of an idea must also be met.

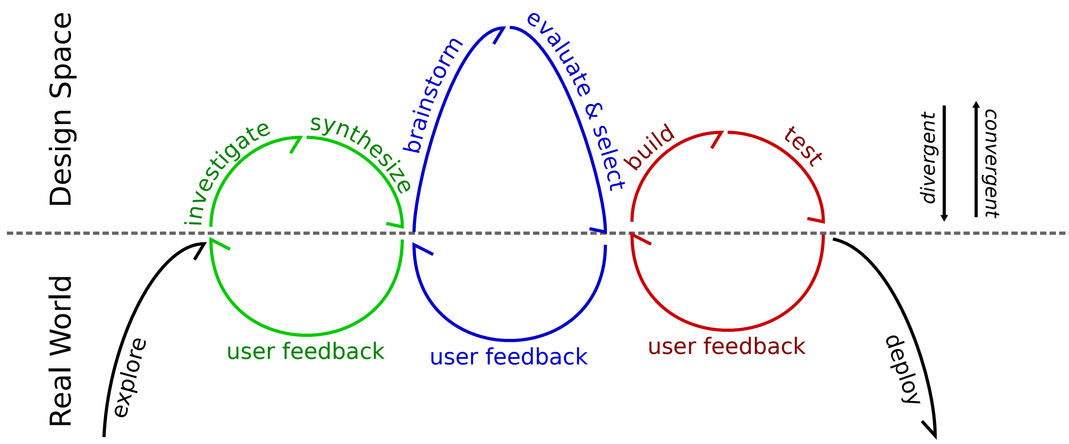

Figure 1: The engineering design process as taught in our week-long workshop. The workshop is broken into three stages: Investigate (green), Ideate (blue), and Prototype (red). In each stage, students are trained to start with divergent thinking (lines that head further into the "design space"), continue with convergent thinking (lines that head toward the real world), and to test all of their design decisions by taking them back to the real world to get feedback. The iterative nature of design is also shown by the various cycles in the design.

In addition to teaching the basics of engineering design thinking, the workshop served several non-technical but crucial needs of the program. First, the teams were arranged for the workshop so that students from both institutions could immediately start working together and developing common ground and teamwork skills. Thus, the workshop served as an 'ice-breaker' to the summer's activities. The workshop also emphasized both visual and verbal communication skills, allowing all of the students to become comfortable expressing their ideas to each other. Finally, the design workshop exposed students to more than just "how" to design, it showed them "why."

The final days of the workshop coincided with the 4th Annual *HKUST One Million Dollar Entrepreneurship Competition*. While it was not initially planned, the students' attendance at the competition proved to be serendipitous, as they were able to immediately apply the design lessons they learned in the workshop to the contestants' already implemented designs. For example, one module of the Design Workshop was about feasibility analysis while generating a list of potential solutions. In this activity, students were taught how to use dimensional analysis, the laws of thermodynamics, and proper prior art searches to determine if an idea was viable under technological, economical, and usability constraints. Later that week, students were able to apply their skills to several of the projects competing for the entrepreneurship prize. They used thermodynamic principles to evaluate a thermoelectric cooling company and found some flaws with the pricing strategy and intended market of a small-scale wind-turbine startup. In several cases, the students arrived at the same conclusions surrounding economic or user-centric issues as the competition's judges. In addition to evaluating the different entrants' design merits, the students also had strong opinions of how each of the teams presented their projects. From the short poster presentations to the longer business pitches, the program participants were able to use what they learned from the Design Workshop to provide constructive criticism of the presentations' structure, delivery, and content.

Summer Long Design Projects

After the conclusion of the Design Workshop, the students were presented with the challenge that they would spend the summer tackling: Visible Light Communication (VLC). VLC is a developing field in which the existing lighting infrastructure is used to transmit digital data in addition to its primary purpose of illumination.[10] The emergence of low-power and affordable Indium Gallium Nitride white LEDs has only recently made this technology economically viable.[11] Currently, VLC has been used in applications including Wireless Local Area Networks, building-to-building wireless links, spacecraft-to-satellite links, and even traffic control.[12, 13] In addition, the faculty members from both institutions that were involved in the program had a wealth of experience in photonics and VLC.

Students were tasked to research the problem, learn from experts in the field, generate possible solution paths, iterating multiple cycles of the design-build-test-refine-present process in a period of nine weeks. After their initial research, the students chose to focus on two application areas: miner location tracking and door security using mobile phones. All eight students in the program worked on the core technology needed to transmit and receive data using LEDs together, and two sub-teams worked on adapting the common technology to the two different applications.

The students divided the common technology into analog and digital subsystems based on the specifications they developed for both of the target applications. The analog subsystem used a phototransistor (light sensor) along with amplification circuitry to detect the transmitted data. The team had to repeatedly refine the design as they found that their original implementation was not robust to changes in the ambient light level. After feedback from design reviews, the design evolved to include an appropriately specified band pass filter that rejected signals outside the modulation bandwidth. This greatly improved the reliability and robustness of the detection circuitry.

The students also designed a digital circuit and software using an Arduino microcontroller that converted the visible light signals into data that could be read by a computer. After consulting with the teaching staff, the students pursued a strategy of researching potential solutions and evaluating them based on a variety of engineering factors. Students explored and learned about many standard modulation schemes (Binary Phase Shift Keying, Pulse Amplitude Modulation, Quadrature Amplitude Modulation, etc.). While the staff advised using a Pugh based decision matrix, students instead chose to use the simplest of the modulation schemes, Binary Phase Shift Keying, based on time management constraints. The students' tests determined that this method was sufficient for their proof of concept prototype. This design decision proved an interesting example of a compromise between the technique taught to the students and the practical constraints of a real design project.

The miner location tracking team also had to build a VLC transmitter circuit that could drive a miner's headlamp using similar techniques. The system communicated with a software program that displayed the miner's identity and location on a user interface shown in Figure 2a. The door security team had to build additional circuitry to control a door-locking mechanism shown in Figure 2b. They also wrote their own Android app that used the phone camera's LED flash to transmit the VLC signal. The students developed a quantitative specification for how secure their system was in terms of the mean number of brute-force (random guess) attacks the system could sustain before failure (a variant of mean time before failure). The students also developed a quantitative specification for the usability of the interface in terms of both the number of inputs (button presses, swipes, etc.) and the total amount of time it would take the user to unlock the door. At the end of nine weeks, both groups presented to members of the SEAS and HKUST communities with the final prototypes shown in Figure 2.

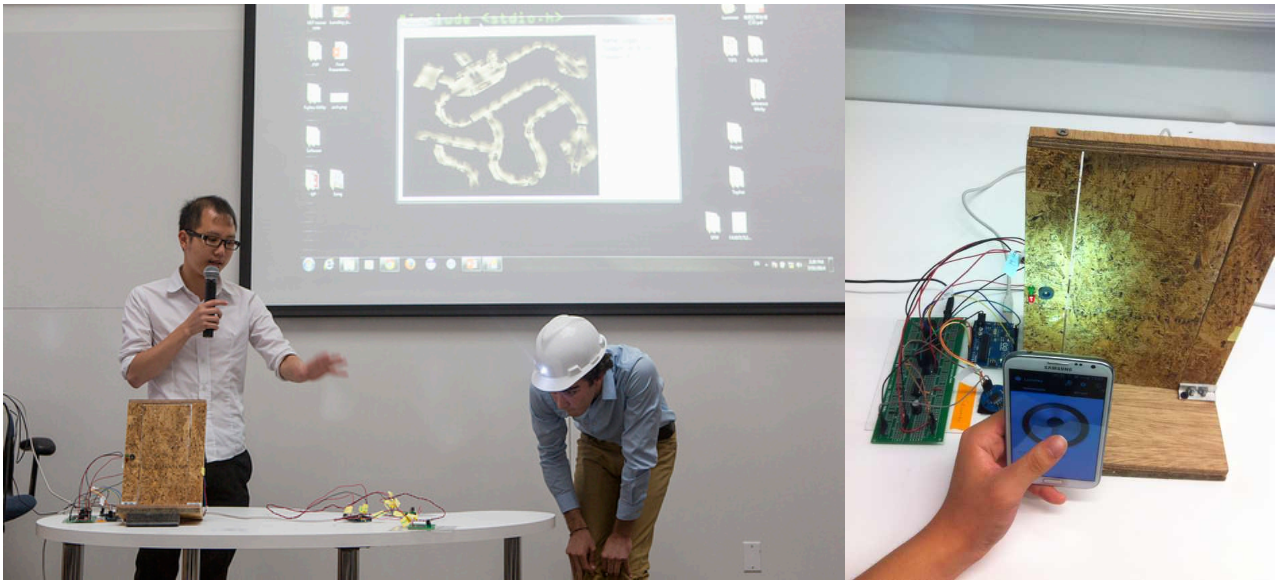

Figure 2: a) Miner Location Tracking via VLC (left) and, b) Door Security using Mobile Phones and VLC (right). Photo Credit: Eliza Grinnell (left) and Tian Zhang (right).

Program Assessment

Self-efficacy refers to individuals' judgment of their capability to organize and execute courses of action for a given task.[14, 15] It is believed that a combination of cognitive (personal goals, self-evaluation of performance, and quality of analytical thinking), environmental (level of challenge and circumstances under which the act takes place), and behavioral (choices that are executed) factors all contribute to self-efficacy.[16] Higher levels of self-efficacy have been correlated to individual students setting higher standards for themselves as well as an increased ability to cope with obstacles. At the completion of the summer program, student feedback about their experience was collected. There were a total of eight participants, four from Harvard and four from HKUST. The two female participants were from Harvard. There was an approximately even split between mechanical and electrical engineering students. Most students indicated that they were interested in international experiences before applying.

First, the participants' responses to the ten self-efficacy questions from the pre- and post-self-efficacy test were compared. There were no significant differences between the men and women in terms of their average self-efficacy score (female = 63.33 ± 18.86, male = 74.00 ± 3.74). Both groups reported improved average scores after the program (female = 86.67 ± 6.29, male = 86.67 ± 5.15). The largest gains were made by the women in the group in the category c*onstruct a prototype* (pre = 45.00 ± 21.21, post = 80.00 ± 0.00). In addition, there were no significant differences in self-efficacy dependent on institution (Harvard = 68.89 ± 13.15, HKUST = 73.70 ± 2.80). Both groups again saw an improvement in their average self-efficacy scores (Harvard = 88.61 ± 4.29, HKUST = 84.07 ± 5.25). In addition, the Harvard group experienced the biggest gains in *constructing a prototype* (pre = 57.50 ± 25.00, post = 82.50 ± 9.57), whereas the

HKUST groups gained the most in *redesign* (pre = 63.33 ± 5.77, post = 83.33 ± 5.77). There are no significant differences between the majors (Mechanical Engineering n = 4, Applied Math n = 1, Electrical Engineering n = 2).

Lastly, students were asked whether they changed their views of pursuing graduate degrees after graduation. There is no significant difference between the pre-self-efficacy measures and changes in views towards graduate school, $F(2,7) = 0.48$, $p > 0.789$. This may indicate that self-directed opportunities during the undergraduate curriculum can be viewed as supplemental, but not necessarily as a way to introduce graduate research habits. Since the students were not working with any graduate students. Figure 3 shows students' self-efficacy scores before and after completing the summer program (n=7).

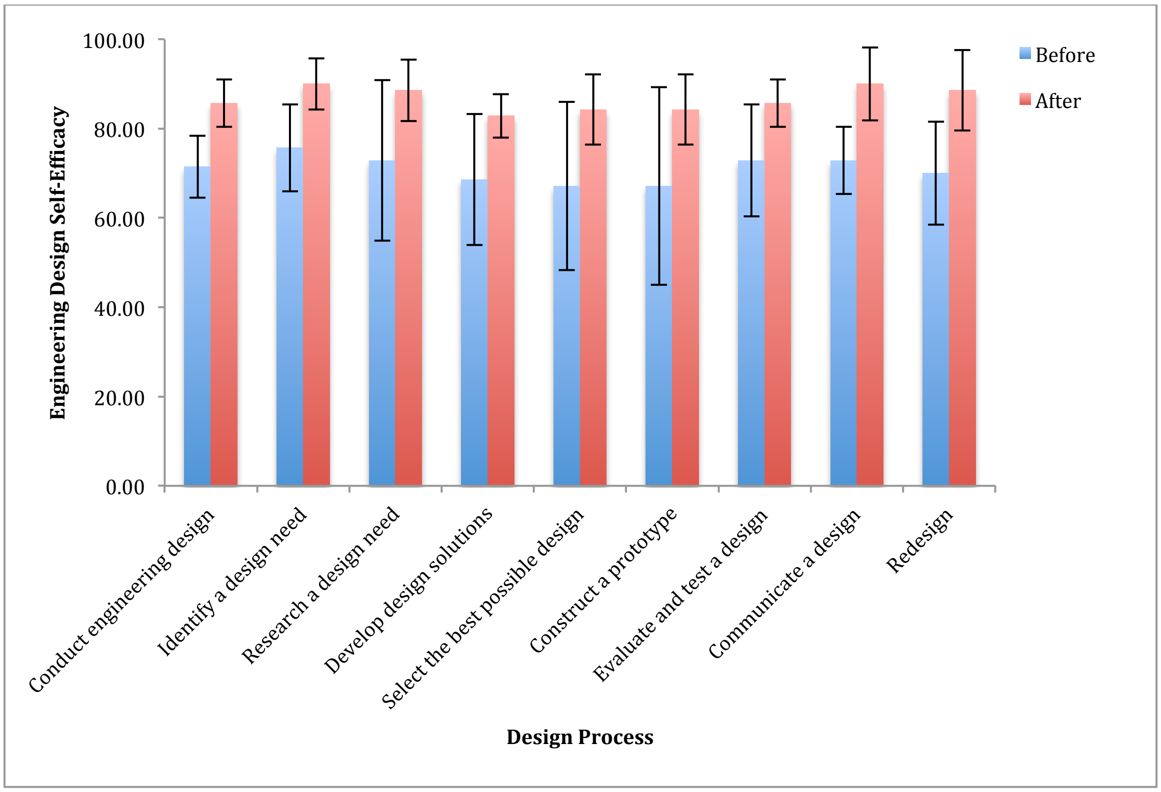

Figure 3: Self-Efficacy scores before and after the program. There is no significant difference (n=7).

Student Feedback

Most of the student feedback centered on lifestyle, not necessarily on the technical details of the program. Overall, students were highly satisfied with the program and would like to see the program extended beyond 2 months. Some students expressed the desire for more advising or mentoring during the project, which was particularly true for more of the HKUST students. The HKUST students in particular would have liked to see an introductory session to inform the participants of the specific topic before the summer. The Harvard students most enjoyed the international exchange portion when asked about the summer experience, while the HKUST students enjoyed the technical aspects of the program the most.

Program Revisions

Having completed the first offering of the Harvard-HKUST International Design Experience, the program staff has examined some areas for future improvement. This program was only offered to four Harvard students, which represents less than 2% of our engineering student population. If the instructional staff hopes to have a material impact on the more than a few students per year, a way to sustainably scale up this summer program in conjunction with other international experiences needs to be considered. At this point in time, students are not given course credit for this program. One option that could facilitate the scaling of the summer program could be to offer course credit for this summer experience in which resources typically used for academic courses could be utilized. Another mechanism to facilitate scaling of the summer experience would be to utilize previous program participants as project mentors. This would enable those mentors to continue to refine their design thinking and prototyping skill in the context of multicultural team projects.

Summary

Opportunities for skill mastery do not occur unless individual students have had both foundational and growth experiences. Knowing an individual's self-efficacy and understanding how it affects his or her learning expands engineering education assessment. The motivation behind the Harvard-HKUST International Design Experience program was to give engineering students on both campuses an opportunity to participate in a meaningful, multicultural engineering design experience during the summer. In addition, this program presented some aspects of the formal design process, taught prototyping skills, and allowed students to refine these skills throughout the course of a summer design project. Beyond immersing the students in engineering design, the goal of this experience was for program participants to learn how to carry out an open ended project and to participate in multicultural design teams in which approaches and views will be different. Nine weeks may not give students enough time to effect changes in their outlook, growth in understanding of different thought processes, or approaches and habits - but part of the 'design' of this program was to capture those elements as much as possible.

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